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Continuation Study of Seepage Quality through Reclamation of Pyrrhotite Tailings by Establishing a Marshland

(Final Report)

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for
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34 pp

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Abstract

A large surface impoundment of sulfide-rich pyrrhotite tailings was divided into eight plots in 1986. Five plots were covered with different mixtures of bog peat, lime ($Ca(OH)_2$) and fertilizer, one plot had woodchips, another had domestic sewage and the final plot was untreated. The plots (except for the sewage plot) were flooded with water and seepage water was sampled using in situ vacuum tensiometers. The seepage water was analyzed for concentrations of SO_4, Fe, Ni, Cu and pH. This report deals with the data collected in the summer and fall of 1988.

The concentrations of SO_4, heavy metals and H^+ ion collected in 1987 (Griffiths, 1987) and in 1988 for each of the plots were compared between the years to see if there had been any improvement in the seepage water quality. Most of the between-year comparisons of parameter concentrations were found not to be significantly different thus indicating no appreciable improvement in the seepage water quality over the relatively short time frame of two years. Using only the 1988 data, between-plot comparisons of the parameter concentrations showed that some treatment covers were significantly different from the others. However, fewer differences were observed from the previous year. On a simple ranking basis however, the treatment cover composed of peat, lime and fertilizer ranked best. Any observed differences in the parameter concentrations between the plots could not be correlated with the

amounts of water used to flood the plots thereby negating the possibility that the differences could be explained by simple dilution.

Comparison of the 1987 and 1988 loading rates of the parameters (mg/day/m^2) within each plot revealed that most of the 1988 loading rates were greater than 1987 loading rates. This was attributed to the reportedly greater use of water in 1988. Between-plot comparisons of the 1988 data revealed that some treatment covers were significantly better than others at reducing the loading rates of the parameters. Overall, plots 3 and 7 ranked best.

Some of the plots were then limed with $Ca(OH)_2$ at rates of 5, 10 and 15 tonnes/ha. Comparisons of the pre- and post-treatment data revealed no significant differences within the same plots for the short test period. Some differences between plots did exist but they were not consistent with the rates of lime application.

RÉSUMÉ

En 1986, un parc â résidus miniers sulfureux â haute teneur en pyrrhotite a été divisé en huit parcelles. Cinq parcelles furent recouvertes avec différents mélanges de tourbe, de chaux ($Ca(OH)_2$) et d'engrais, une parcelle fut recouverte de sciure de bois, une autre de déchets domestiques et une dernière fut préservée intacte. Les parcelles (sauf pour celle recouverte de déchets domestiques) furent inondées et l'eau de lixiviation fut échantillonnée avec l'aide de tensiomèters â vacuum in situ. L'eau de lixiviation fut analysée pour déterminer les concentrations de SO_4, Fe, Ni, Cu et pH. Ce rapport porte sur l'information recueillie pendant l'été et l'automne 1988.

Les concentrations de SO_4, de métaux lourds et de H^+ dans les échantillons recueillis en 1987 (Griffiths, 1987) et 1988 dans chacunes des parcelles furent comparées afin de vérifier si une amélioration de la qualité de l'eau avait eu lieu entre 1987 et 1988. La plupart des comparaisons entre les concentrations des paramètres ne montrèrent par de grandes differénces entre les concentrations, n'indiquant pas d'amélioration de la qualité de l'eau au court des deux ans d'expérimentation. Utilisant uniquement les données de 1988, des comparaisons de concentrations des paramètres entre les parcelles montrèrent que certains recouvrements se comportaient différement des autres. Toutefois, les differénces ne furent pas aussi grandes dans le cas de l'année précédente (1987).

Le meillieur rendement fur obtenu avec le recouvrement composé de tourbe, chaux et engrais. Les différences des concentrations observées entre les parcelles ne purent être corrélées avec les quantités d'eau utilisées pour inonder les parcelles, ce qui n'excluerait donc pas la possibilité que les différences puissent être causées par dilution.

Des comparaisons entre les taux de charge des paramètres ($mg/j/m^2$) en 1987 et 1988 dans chaque parcelle ont révélé que la plupart des charges de 1988 furent supérieures â celles de 1987. Ce phénomène fut attribué au fait qu'une plus grande quantité d'eau fut utilisée en 1988. Des comparaisons entre les données provenant de différentes parcelles en 1988 ont révélé que certains recouvrements sont supérieurs aux autres pour réduire les taux de charge des paramètres. En tout et partout, les parcelles no. 3 et 7 furent supérieures.

Quelques unes des parcelles furent chaulées avec le $Ca(OH)_2$ â des taux de 5, 10 et 15 tonnes/ha. Des comparaisons de données pré- et post-traitement n'ont révélé aucune différence significative au niveau des parcelles pour le court intervalle étudie. Certaines différences entre les parcelles furent décelées mais elles ne semblaient pas liées aux taux d'application de chaux.

Introduction

Mine and mill operations produce different waste products through the mining company's efforts to extract and concentrate valuable minerals from the waste host rock. Waste products produced by Falconbridge Ltd. such as pyrrhotite (Fe_7S_8) and tailing (mostly inert silicates) are disposed of in surface impoundments. Upon abandonment however, surface runoff from the deposits contaminates the surrounding area thereby detrimentally affecting the local faunal and floral life. Consequently, there has been much interest in means by which the effects and problems associated with surface impoundments of tailings could be ameliorated.

Sulfide-rich tailings are of particular concern because upon oxidation, they become acid generators. Water from precipitation or surface runoff and atmospheric oxygen combine with the reduced sulfides to produce sulfuric acid. Since non-recoverable concentrations of iron, nickel and copper are present in the Falconbridge tailings are readily dissolved in acidic water, runoff from the tailing impoundments is injurious to fauna and flora. This is strikingly obvious by the lack of plant life on sulfide-rich tailings.

Water and oxygen are the two necessary substrates for acid production by the tailings: should either be absent, acid production is inhibited. Different methods have been proposed to

reduce acid production including placing the tailings under the cover of water and vegetation. Vegetative cover has to date been the accepted method because humus decomposition used up the oxygen, the cover reduces dust and the process of vegetative growth is regenerative which would in the future allow the company to walk away from the site without concern. Unfortunately, this method has not always been sufficiently effective to allow a walk-away strategy.

The Fault Lake pyrrhotite-tailing deposit in Falconbridge, Ontario has been the site of previous experimentation whereby different marshland compositions have been used in an attempt to reduce acid-generation and acidic runoff from the site. The installation of the marshland treatment covers and sampling vacuum tensiometers are described in Skraba & Winterhalder (1987). It was only possible for four samples to be taken immediately after the installations in 1986 although a complete summer's data was collected in 1987 by Griffiths (1987). The purpose of this year's continuation of the sampling program was to test whether or not the marshland treatment covers would improve the quality of the runoff over time. In addition, after sufficient samples were taken in order that comparisons of the 1988 and 1987 data could be made, liming of some of the plots was done to see if the results could be improved.

Materials and Methods

The treatment plots were not changed from their initial set up in 1986 (Skraba & Winterhalder, 1987). The treatment plots are described in Table 1 and Figure 1. The set up of the sampling vacuum tensiometers is shown in Figure 2. Test plot #6 was not sampled during 1988 and sewage addition was discontinued. This plot may be resampled in 1989.

Table 1. Treatments applied to the test plots.

Plot	Area (m^2)	Treatment	Flow rates ($L/day/m^2$)	Flow rates + Precipitation[a]
1	860	10 cm stone[b] + 30 cm bog peat	135.6	138.4
2	740	60 cm bog peat	74.0	76.8
3	980	30 cm bog peat + lime[c] + fertilizer[d]	37.4	40.2
4	2080	30 cm bog peat	54.4	57.2
5	1710	30 cm bog peat + lime[c]	31.2	34.0
6[e]	1280	approx. 40 cm domestic sewage sludge		
7	1360	30 cm wood chips	19.0	21.8
8	580	no treatment (control)	188.5	191.3

Note: a) Total precipitation for June to September (1988) was 323.7 mm which is equivalent to an average of 2.8 $L/day/m^2$.
b) Stones ranged in size from 5 to 15 cm.
c) Lime was applied at a rate of 5 tonnes/ha.
d) Fertilizer was applied at a rate of 400 kg/ha.
e) Not tested this year.

Flooding of the plots with water pumped up from a nearby pothole lake was started on June 2, 1988. The flow were adjusted to produce even flooding over all of the plots. Initially, the flows were high so as to wash away the effects of leaving the plots unwatered since September 1987 after the previous year's data collection had been completed. After the initial flooding period

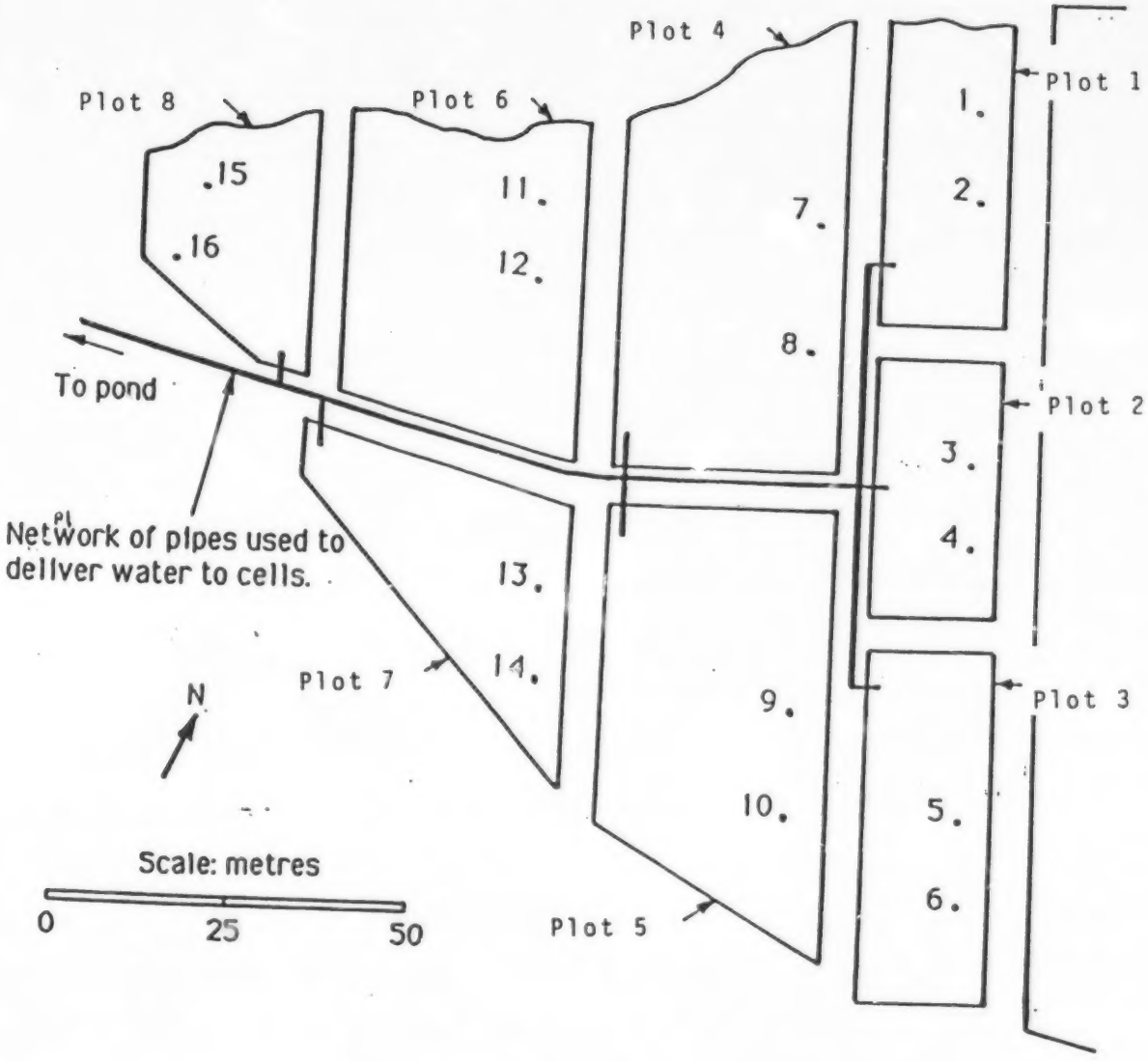

Figure 1. View of experimental site showing the location of the treatment plots and lysimeters.

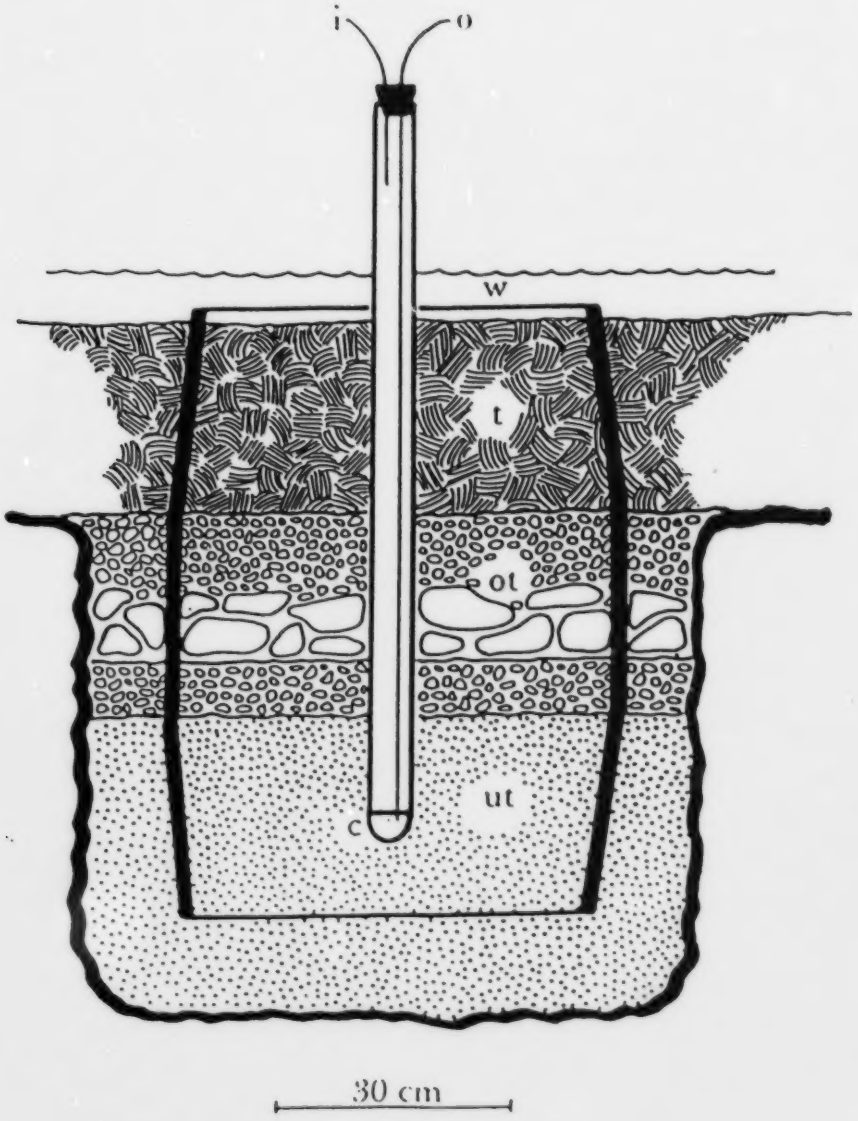

Figure 2. Vacuum tensiometer installation. A hole was dug into the tailings into which an open-ended plastic barrel was lowered. The lowermost portion of the hole and barrel was backfilled with unoxidised tailiings (ut) thereby burying the ceramic cup (c) of the vacuum tensiometer. Oxidised tailings (ot) were used to backfill the hole and barrel to ground level. The marshland treatment cover (t) was then spread on the tailings and water (w) flooded the plot. Samples were extracted from the vacuum tensiometer via the outlet tube (o) while pressurised N_2 gas was fed through the inlet tube (i) to assist collection of the sample.

(which lasted to June 15), the flows were reduced to moderate levels and more accurately adjusted to compensate for individual plot requirements depending on the size of the plot and the loss of water down through the ground, laterally through the berm and by evapouration.

Shortly after the flooding had been initiated, the vacuum tensiometers were purged with N_2 gas and checked for damage or deterioration. They were repaired or replaced as necessary.

Sampling followed the procedure used in the previous years. The N_2 bottle was connected to the large tube running through the plug on the top of the vacuum tensiometer. Since the vacuum tensiometers had been placed in a partial vacuum after the previous sample had been taken, the first step was to replace the partial vacuum with N_2 gas. The N_2 gas also was used to apply positive pressure to the water in the vacuum tensiometer to aid its collection. The sampling tube was connected to a 1000 mL Erlenmeyer flask which was further connected to a Nalgene^{tm} hand vacuum pump. The pump was used to draw the water out of the vacuum tensiometer into the flask. The N_2 gas was used to expel O_2 gas from the vacuum tensiometer thereby preventing the potential of introducing oxygen to the tailings. After collection of the sample, the vacuum tensiometer was put in a partial vacuum of approximately 50 cm Hg negative pressure (50 kPa) and sealed until the next sample was taken. The vacuum assisted the collection of

water from the surrounding area by drawing water into the vacuum tensiometer.

The water samples were analyzed for concentrations of SO_4 (after oxidation), unfiltered Fe, Ni and Cu concentrations and pH. Some samples contained too little water to be completely analyzed and consequently some parameters (most commonly pH and SO_4) were not measured. When it was found that some vacuum tensiometers were consistently providing smaller and smaller volumes of water, the sample volumes were measured and recorded. Recommendations for replacement of these vacuum tensiometers will be made later.

Loading data ($mg/day/m^2$) were calculated by multiplying the concentrations of the parameters (mg/L) by the flow of water to the respective plots ($L/day/m^2$). In addition, local rainfall data were obtained from the Atmospheric Environment Service at the Sudbury Airport and added to the volume of pumped water for loading determinations.

On September 24, some of the plots were limed using a slurry of water and lime ($Ca(OH)_2$). Plots 3 and 7 were limed at an application rate of 5 tonnes/ha, Plot 1 was limed at an application rate of 10 tonnes/ha, Plot 2 was limed at an application rate of 15 tonnes/ha and Plot 5 was untreated and served as the control. Accurate flow measurements were not kept in October so loadings could not be calculated for post-treatment samples. Samples were

taken until October 27, 1988.

Statistical analyses of the results were performed using STATGRAPHICS[tm], a computer statistics program. Additional analyses followed the procedures outlined in Zar (1984). Data from 1987 were obtained in order that comparisons between years could be made. The data taken from 1987 were only those from sampling days 49 to 105 during which time the plots had been well flooded.

Results

The concentrations of the parameters measured before and after the plots were limed are shown in Table 2. The lake water used for flooding the plots was of better quality than the waters sampled from any of the plots.

Using the Kolmogorov-Smirnov goodness of fit test, the data were found not to be normally distributed thus requiring either transformation or the use of nonparametric tests for determination of differences.

The 1988 pre-treatment data were compared with the 1987 data. Before comparisons could be made, the concentrations were transformed using the natural logarithms of the values. A comparison was then made using t-tests (Table 3). Most of the results were not significantly different from year to year and where differences existed, slightly less than half of the 1988 data were greater than 1987, the rest of the 1988 results were less than 1987. The 1988 data were then compared between plots (Table 4). The data used were untransformed and compared using Dunn's multiple range test on Kruskal-Wallis ranks (Zar, 1984). Some plots were significantly different from others. Plot 3 ranked best in terms of the concentrations of the parameters measured in the samples.

The possibility that any observed differences in the

Table 2. Concentrations of parameters in the water sampled from the lysimeters and the water source. Data are given as mean ± S.E.M. in units of ppm except H^+ ion concentrations which are given in millimoles.

A) Before liming

Plot	Treatment	SO_4	Fe	Ni	Cu	H^+ ion	pH
LW	Lake water	40.7 ± 1.3	0.0 ± 0.0	0.05 ± 0.01	0.020 ± 0.010	0.19 ± 0.19	6.10 ± 1.43
1	Stone + Peat	5783 ± 722	1657 ± 433	0.63 ± 0.18	0.153 ± 0.091	0.97 ± 0.22	3.12 ± 0.09
2	Peat + Peat	1297 ± 136	856 ± 141	6.99 ± 3.23	0.090 ± 0.031	1.22 ± 0.26	2.97 ± 0.09
3	Peat + Lime + Fertilizer	3050 ± 95	711 ± 60	0.52 ± 0.12	0.039 ± 0.009	0.29 ± 0.08	3.28 ± 0.18
4	Peat		1467 ± 592	0.54 ± 0.07	0.123 ± 0.050	1.26 ± 0.00	2.90 ± 0.00
5	Peat + Lime	5990 ± 1535	3136 ± 565	0.93 ± 0.30	0.069 ± 0.023	0.86 ± 0.10	3.08 ± 0.05
7	Wood chips	6051 ± 519	3555 ± 221	0.89 ± 0.20	0.034 ± 0.004	0.61 ± 0.09	3.27 ± 0.06
8	No treatment	5010 ± 758	1644 ± 436	1.06 ± 0.21	0.088 ± 0.012	1.19 ± 0.23	2.95 ± 0.08

B) After liming

Plot	Treatment	SO_4	Fe	Ni	Cu	H^+ ion	pH
1	10 tonnes lime/ha	3763 ± 1306	2083 ± 704	0.37 ± 0.02	0.040 ± 0.000	0.41 ± 0.05	3.40 ± 0.06
2	15 tonnes lime/ha	1060 ± 102	526 ± 68	1.93 ± 1.69	0.100 ± 0.080	0.93 ± 0.33	3.00 ± 0.09
3	5 tonnes lime/ha	3240 ± 297	655 ± 225	0.29 ± 0.10	0.053 ± 0.026	0.43 ± 0.17	3.25 ± 0.27
5	Control	2010 ± 322	1069 ± 478	0.37 ± 0.13	0.120 ± 0.094	1.23 ± 0.35	3.00 ± 1.43
7	5 tonnes lime/ha	9313 ± 1619	3370 ± 757	0.54 ± 0.08	0.045 ± 0.010	1.19 ± 0.14	3.22 ± 0.19

Table 3. Comparisons of 1988 and 1987 concentration data using t-tests (p = 0.05) for each parameter and plot. NDS = not significantly different, 88>87 = 1988 data significantly greater than 1987 data, 88<87 = 1988 data significantly less than 1987 data.

Parameters	Plots 1	2	3	4	5	7	8
SO_4	NSD	88<87	88<87		NSD	88>87	NSD
Fe	NSD	88<87	88<87	NSD	NSD	88>87	NSD
Ni	NSD	88>87	88>87	NSD	88>87	88>87	NSD
Cu	NSD	NSD	NSD	88>87	NSD	NSD	88>87
H^+ ion	NSD	NSD	88<87		NSD	NSD	NSD

Note: Treatments in plots are as follows: 1 - Stone + Peat; 2 - Peat + Peat; 3 - Peat + Lime + Fertilizer; 4 - Peat; 5 - Peat + Lime; 7 - Wood Chips; 8 - No Treatment.

Table 4. Comparisons of concentrations of parameters from all plots using samples taken before liming took place. Plots underlined with a common line were found not to be significantly different (p = 0.05). Concentrations increase from left to right.

Parameters	Plots						
SO_4	2	3	8	5	1	7	
Fe	3	2	4	1	8	5	7
Ni	3	1	4	5	7	8	2
Cu	3	7	5	1	2	8	4
H^+ ion	3	7	1	5	2	8	4

Note: Treatments in plots are as follows: 1 - Stone + Peat; 2 - Peat + Peat; 3 - Peat + Lime + Fertilizer; 4 - Peat; 5 - Peat + Lime; 7 - Wood Chips; 8 - No Treatment.

concentrations of the parameters may be explained by simple dilution was tested by determining the correlations between flow rates (Table 1) and average concentrations of the parameters (Table 2). The results are given in Table 5. For all parameters, there were not significant correlations between flow rates and the average concentrations of the parameters.

Table 5. Correlation coefficients for relationships between flow rates (including precipitation; taken from Table 1) and the average concentrations of the parameters (taken from Table 2). P is the probability that the data is correlated: when $P \geq 0.95$, the correlation is statistically significant.

Data	Correlation Coefficient	Probability
Flow vs SO_4	$R^2 = 0.0037$	$P = 0.0917$
Flow vs Fe	$R^2 = 0.1106$	$P = 0.5339$
Flow vs Ni	$R^2 = 0.0000$	$P = 0.0102$
Flow vs Cu	$R^2 = 0.3094$	$P = 0.8053$
Flow vs H^+ ion	$R^2 = 0.2702$	$P = 0.7683$

The data were then converted into loading of the parameters from the plots for both 1988 and 1987 (Table 6). The water usage in 1988 was greater than that of 1987 even if one discounts the input of precipitation. The loading values were then transformed using natural logarithms of the values and compared by year using t-tests (Table 7). In all but a few cases, the 1988 loadings were greater than that of 1987. In only one case (Plot 2, SO_4) was the 1987 loading greater than the 1988 loading. The untransformed 1988 data was then compared between plots using Dunn's multiple range test on Kruskal-Wallis ranks (Table 8). Although there were

Table 6. Loading of parameters into the environment from the test plots. Data are given as mean ± S.E.M. Units for flows are given as L/day/m^2, for SO_4 and Fe are g/day/m^2, for Ni and Cu are mg/day/m^2 and for H^+ ion are millimol/day/m^2.

A) Data collected in 1988

Plot	Treatment	Flows	SO_4	Fe	Ni	Cu	H^+ ion
1	Stone + Peat	138.4	800.4 ± 99.9	229.3 ± 59.9	87.2 ± 25.0	21.2 ± 12.6	133.8 ± 30.9
2	Peat + Peat	76.8	99.6 ± 10.4	65.7 ± 10.9	537.4 ± 248.3	6.9 ± 2.3	93.4 ± 19.8
3	Peat + Lime + Fertilizer	40.2	122.6 ± 3.8	28.6 ± 2.4	20.8 ± 4.9	1.6 ± 0.3	11.7 ± 3.2
4	Peat	57.2		83.9 ± 33.9	30.7 ± 4.0	7.1 ± 2.9	72.0 ± 0.0
5	Peat + Lime	34.0	203.7 ± 52.1	106.6 ± 19.2	31.7 ± 10.1	2.3 ± 0.8	29.2 ± 3.5
7	Wood chips	21.8	131.9 ± 11.3	77.5 ± 4.8	19.5 ± 4.3	0.7 ± 0.1	13.3 ± 2.0
8	No treatment	191.3	958.4 ± 145.1	314.5 ± 83.3	198.2 ± 39.3	16.8 ± 2.4	226.9 ± 43.5

B) Data collected in 1987

Plot	Treatment	Flows	SO_4	Fe	Ni	Cu	H^+ ion
1	Stone + Peat	54.7	224.8 ± 28.9	101.5 ± 16.0	9.8 ± 1.0	2.6 ± 0.7	46.2 ± 7.2
2	Peat + Peat	34.6	194.6 ± 13.5	69.8 ± 14.8	6.0 ± 0.2	1.2 ± 0.1	33.2 ± 4.5
3	Peat + Lime + Fertilizer	21.6	96.6 ± 9.8	43.8 ± 5.6	3.4 ± 0.3	0.7 ± 0.1	14.8 ± 1.8
4	Peat	18.7	120.4 ± 3.2	57.1 ± 3.5	8.6 ± 1.8	0.6 ± 0.1	20.0 ± 3.0
5	Peat + Lime	15.8	86.7 ± 11.6	40.8 ± 6.7	2.5 ± 0.2	0.5 ± 0.1	15.7 ± 0.8
7	Wood chips	18.7	54.7 ± 5.3	24.9 ± 3.7	3.0 ± 0.4	0.4 ± 0.1	10.4 ± 1.9
8	No treatment	64.8	348.2 ± 68.6	156.0 ± 41.5	71.4 ± 38.9	1.7 ± 0.4	60.9 ± 9.4

Note: Flow rates for 1987 were recalculated from rates given in Table 1 (Michelutti, 1988; p. 2) and loading data for 1987 was calculated using parameter concentrations from days 49 to 105.

Table 7. Comparisons of 1988 and 1987 loading data using t-tests (p = 0.05) for each parameter and plot. NSD = not significantly different, 88>87 = 1988 data significantly greater that 1987 data, 88<87 = 1988 data significantly less than 1987 data.

Parameters	Plots 1	2	3	4	5	7	8
SO_4	88>87	88<87	88>87		NSD	88>87	88>87
Fe	NSD	NSD	88>87	NSD	88>87	88>87	NSD
Ni	88>87	88>87	88>87	88>87	88>87	88>87	88>87
Cu	88>87	88>87	NSD	88>87	88>87	88>87	88>87
H^+ ion	88>87	88>87	NSD		88>87	NSD	88>87

Note: Treatments in plots are as follows: 1 - Stone + Peat; 2 - Peat + Peat; 3 - Peat + Lime + Fertilizer; 4 - Peat; 5 - Peat + Lime; 7 - Wood Chips; 8 - No Treatment.

Table 8. Comparisons of loading rates of parameters from all plots using samples taken before liming took place. Plots underlined with a common line were found not to be significantly different (p = 0.05). Loadings increase from left to right.

Parameters	Plots					
SO_4	2	3	7	5	1	8
Fe	3	2	4	7	5	1	8
Ni	7	3	5	4	1	2	8
Cu	7	3	5	2	4	1	8
H^+ ion	3	7	5	2	4	1	8

Note: Treatments in plots are as follows: 1 - Stone + Peat; 2 - Peat + Peat; 3 - Peat + Lime + Fertilizer; 4 - Peat; 5 - Peat + Lime; 7 - Wood Chips; 8 - No Treatment.

differences in the loading rates from some plots, no treatment cover was clearly better than the others. Again on a simple ranking basis, plots 3 and 7 were the two best overall.

The data obtained after liming of the plots took place was compared between plots using the untransformed data and Dunn's multiple range test on Kruskal-Wallis ranks. The results (Table 9) do not show that one plot was consistently better than the rest at reducing the concentrations of the parameters. However, Plot 2 (15 tonnes lime/ha) appears to rank best most often although at no time were the concentrations of the parameters in Plot 2 significantly less than all of the rest.

Table 9. Comparisons of concentrations of parameters from all treated plots using samples taken after liming took place. Plots underlined with a common line were found not to be significantly different ($p = 0.05$). Concentrations increase from left to right.

Parameters	Plots				
SO_4	2	5	1	3	7
		5	1	3	7
Fe	2	3	5	1	7
		3	5	1	7
Ni	3	5	2	1	7
Cu	2	3	5	7	1
H^+ ion	5	2	7	3	1

Note: Marshland treatments in plots are as follows: 1 - Stone + Peat; 2 - Peat + Peat; 3 - Peat + Lime + Fertilizer; 5 - Peat + Lime; 7 - Wood Chips. Additional lime applications to plots are as follows: 1 - 10 tonnes lime/ha; 2 - 15 tonnes lime/ha; 3 - 5 tonnes lime/ha; 5 - 0 tonnes lime/ha (control); 7 - 5 tonnes lime/ha.

The pre- and post-treatment data were compared using transformed data and t-tests (Table 10). In all but 2 cases, there was no improvement achieved by the treatment of the plots by any amount of lime over the pre-treatment levels of the parameters.

Table 10. Comparisons of 1988 concentrations data sampled before and after liming of the plots using t-tests ($p = 0.05$) for each parameter and plot. NSD = not significantly different, B>A = Before liming data significantly greater than After liming data, B<A = Before liming data significantly less than After liming data.

Plots	1	2	3	5	7
Lime (tonnes/ha)	10	15	5	Control	5
Parameters					
SO_4	NSD	NSD	NSD	NSD	B>A
Fe	NSD	NSD	NSD	B>A	NSD
Ni	NSD	NSD	NSD	NSD	NSD
Cu	NSD	NSD	NSD	NSD	NSD
H^+ ion	NSD	NSD	NSD	NSD	NSD

Note: Treatments in plots are as follows: 1 - Stone + Peat; 2 - Peat + Peat; 3 - Peat + Lime + Fertilizer; 5 - Peat + Lime; 7 - Wood Chips.

Discussion

When the project of reclamation of the Fault Lake tailing area was started in 1988, it was thought that the quality of seepage from the marshland treatment plots would have improved over the results obtained in 1987 during the period when the plots were well flooded (days 49 to 105; Griffiths, 1987). Indeed, vegetative growth on the peat-treated plots did thrive and increase but had very little to no visible effect on the seepage from the plots. Griffiths (1987) found that some plots clearly improved the seepage water better than others. However, this was not observed in 1988 although Plot 3, which appeared to rank best both in terms of the concentrations and the loading rates of the parameters, also ranked well in 1987 (second and fourth respectively).

It is surprising that the volume of water pumped from the pothole lake to flood the plots was so much greater in 1988 than in 1987. Because the concerns about last year's dry summer were passed on to me by D. Griffiths, the water use was monitored very closely to prevent the plots from drying out. Nevertheless, the water use increased from 2% (Plot 7) to 191% (Plots 4 and 8). It was for this reason that the loading rates were generally greater in 1988 than the previous year even though the concentrations of the parameters from the sampled waters of the vacuum tensiometers were not much different than before. However, the comparisons of the two years' loading data may be of limited value because the

average water use for 1987 (Table 1.1; Griffiths, 1987) presumably includes the dry period (during which flooding was interrupted) in the calculations as well as the period of greatest interest to this study (days 49 to 105).

A concern was raised that the differences in the concentrations of the parameters may simply be due to dilution of the parameters by the different amounts of water used. However, correlation analysis clearly showed that dilution could not explain the concentration differences. The treatment covers must be responsible for any observed differences in the quality of the seepage waters from the plots.

It was found that the addition of lime to the surface of some plots did not improve the seepage quality of the limed plots, even when the lime was applied at a rate of 15 tonnes/ha. There are three possible explanations for the results; (1) more time was required for the lime to have an effect, (2) the acid generating capacity of the tailings was too great and (3) adsorption of heavy metals (notably iron) to the lime may have inactivated the lime. Although only three samples were taken after liming had taken place, the last sample was taken 33 days after the lime slurry was added to the plots. Observations made in the summer revealed that the plots, after a good flooding, took 2 to 3 days to lose the water from the surface and an additional 2 days for the soil in the untreated (wet control) plot to lose water to the level of the

ceramic cup at the base of the vacuum tensiometer so that no water could be extracted from the ground. It took 2 to 3 days longer in September for the plots to lose their water from the surface. Therefore, the time required for water from the surface to pass through the soil to the level of the ceramic cup would be about 4 to 5 days in the summer and 6 to 7 days in the fall. It appears that the 33 days between liming and the last sample should have been ample time for the lime-containing water to reach the base of the vacuum tensiometers. The second concern is that the acid generating capacity of the tailings may be too great for the buffering capacity of the lime to accommodate. This would have to be tested. Such would explain the fact that there were no differences between the amounts of lime added to the plots because the acid generating capacity of the tailings was greater than any of the lime applications. The third concern is that iron may bind to the lime and make it unavailable. Such has occurred at other water treatment facilities at Falconbridge Ltd. whereby liming did not increase the pH because the lime became bound by iron (Michelutti, 1989; pers. com.)[1]. Since the data collected after lime addition was sparse, subsequent sampling will be undertaken in 1989 and may result in statistically significant results.

In all three reports produced so far, the data seem to suggest that the marshland treatments are able to reduce the loading of the

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[1] R.E. Michelutti, Supervisor of Environmental Control, Falconbridge Nickel Mining Ltd., Sudbury Operations.

parameters on the environment but are unable to reduce the acid-generating capability of the tailings. It is felt that although the additional lime added to some of the plots this year had no noticeable effect on acid-generation by the tailings, further testing should be undertaken. For example, mixtures of tailings and lime at different concentrations should show how much lime would be required to neutralize the acid-generation of tailings material at different depths. Such tests may show that more than an acceptable cost-effective amount of lime would be required to neutralize the acid generated within a specified depth of tailings as was suggested by Maclean & Dekker (1976). A decision at that point would have to be made as to whether or not the treatments should be designed without concern for the pH of the seepage.

It also would be of interest to consider the use of a top soil-grass treatment in addition to the marshland treatments already in place. The rationale for this suggestion stems from the dependence of the marshland treatments on the pumped water which is expensive enough without considering the costs and water requirements that would be necessary should any of the tested treatments be implemented in a large-scale program. Similar requirements would not be necessary for a grassland treatment. Because it was found that the woodchip treatment retained water best, perhaps a combination of a grassland covering a layer of woodchips would provide the system with sufficient water retention for the plant life to thrive and generate humus and soil.

Admittedly, because of the reduced volume of water flowing through the treatments into the tailings, obtaining enough water for analysis of the effects of the treatments would be difficult. Other methods of sampling would have to be examined.

Conclusions

1) There were no significant improvements by the treatment covers on the concentrations of the parameters from 1987 to 1988.

2) The loadings of the parameters were generally significantly greater this year than last mainly because the flow rates of water were greater than that which were reported for 1987.

3) There were few differences between the treatments in their ability to reduce the concentrations of the parameters or the loading rates of the parameters although Plot 3 (Peat + Lime + Fertilizer) fared better than the rest of the plots both in terms of the concentrations and loadings of the parameters. Differences in the concentrations of the parameters were not due to dilution effects.

4) Additional lime when added to some of the plots did not reduce the hydrogen ion concentrations of the treated plots nor were any of the other parameters affected by the additional lime, even when applied at rates of 15 tonnes/ha.

5) Vacuum tensiometers 1, 2, 3, 5, 6, 7, 8 and 10 were found to deteriorate in sampling efficiency through the season and should be replaced before the next repetition of the sampling program is initiated. Records of the sample volumes extracted from the vacuum

tensiometers also should be kept to monitor the condition of the ceramic cap on the bottom of the vacuum tensiometer.

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row	POND	LYSIM	SO4	FE	NI	CU	PH	TREAT	H_ION	WATER
1	01	01					2.70	00	1.99526E-003	138.4
2	01	02					2.70	00	1.99526E-003	138.4
3	02	03						00		76.8
4	02	04	1670	780	1.90	0.22	2.60	00	2.51189E-003	76.8
5	03	05	3370	1040	1.66	0.02	3.40	00	3.98107E-004	40.2
6	03	06						00		40.2
7	04	07						00		57.2
8	04	08						00		57.2
9	05	09						00		34.0
10	05	10						00		34.0
11	07	13	9440	5200	2.36	0.04	2.90	00	1.25893E-003	21.8
12	07	14	6030	2900	0.24	0.01	3.10	00	7.94328E-004	21.8
13	08	15						00		191.3
14	08	16						00		191.3
15	WF	WF	42		0.07	0.01	7.50	NO	3.16228E-008	
16	01	01		1450	2.05	0.95	3.45	00	3.54813E-004	138.4
17	01	02		450	0.26	0.04	3.40	00	3.98107E-004	138.4
18	02	03						00		76.8
19	02	04		438	1.02	0.03	3.30	00	5.01187E-004	76.8
20	03	05	2860	677	0.61	0.03	3.85	00	1.41254E-004	40.2
21	03	06		577	0.36	0.04		00		40.2
22	04	07						00		57.2
23	04	08		322	0.51	0.05		00		57.2
24	05	09						00		34.0
25	05	10		3770	0.57	0.17		00		34.0
26	07	13	2580	3670	0.95	0.04	3.40	00	3.98107E-004	21.8
27	07	14	5550	2660	0.82	0.02	3.60	00	2.51189E-004	21.8
28	08	15						00		191.3
29	08	16						00		191.3
30	WF	WF	38		0.04	0.04	7.55	NO	2.81838E-008	
31	01	01		2000	0.92	0.25	3.10	00	7.94328E-004	138.4
32	01	02		540	0.20	0.03		00		138.4
33	02	03		1700	29.00	0.30		00		76.8
34	02	04		510	1.17	0.03	3.15	00	7.07946E-004	76.8
35	03	05	2800	630	0.47	0.01	3.65	00	2.23872E-004	40.2
36	03	06		610	0.26	0.04		00		40.2
37	04	07						00		57.2
38	04	08		2300	0.67	0.22		00		57.2
39	05	09						00		34.0
40	05	10	9360	4200	0.64	0.09	2.95	00	1.12202E-003	34.0
41	07	13	4900	3600	0.70	0.05	3.10	00	7.94328E-004	21.8
42	07	14	5510		0.61	0.05	3.45	00	3.54813E-004	21.8
43	08	15						00		191.3
44	08	16	6810	2800	0.61	0.06	3.00	00	1.00000E-003	191.3
45	WF	WF						NO		
46	01	01	4550	2500	0.73	0.09	3.35	00	4.46684E-004	138.4
47	01	02		580	0.15	0.03	3.40	00	3.98107E-004	138.4
48	02	03		1450	21.00	0.12	2.90	00	1.25893E-003	76.8
49	02	04	1300	570	0.78	0.02	2.85	00	1.41254E-003	76.8
50	03	05	2910	800	0.45	0.01	3.20	00	6.30957E-004	40.2
51	03	06		610	0.35	0.08		00		40.2

row	POND	LYSIM	SO4	FE	NI	CU	PH	TREAT	H_ION	WATER
52	04	07						00		57.2
53	04	08						00		57.2
54	05	09						00		34.0
55	05	10	8210	4270	0.44	0.04	2.95	00	1.12202E-003	34.0
56	07	13		3660	0.63	0.03	2.95	00	1.12202E-003	21.8
57	07	14	5500	2720	0.50	0.02	3.35	00	4.46684E-004	21.8
58	08	15						00		191.3
59	08	16	5610	2400	1.06	0.10	2.90	00	1.25893E-003	191.3
60	WF	WF	42		0.05	0.01	3.25	NO	5.62341E-004	
61	01	01	5750	3520	0.65	0.05	3.00	00	1.00000E-003	138.4
62	01	02		620	0.63	0.05	2.65	00	2.23872E-003	138.4
63	02	03		980	2.53	0.02		00		76.8
64	02	04	1030	370	0.54	0.04	2.85	00	1.41254E-003	76.8
65	03	05	3090	890	0.62	0.07	2.65	00	2.23872E-003	40.2
66	03	06		710	0.40	0.09		00		40.2
67	04	07						00		57.2
68	04	08		1780	0.43	0.10	2.90	00	1.25893E-003	57.2
69	05	09	2820	1290	2.34	0.02	3.25	00	5.62341E-004	34.0
70	05	10		3760	1.74	0.12	3.15	00	7.07946E-004	34.0
71	07	13	6870	3870	0.50	0.05	3.20	00	6.30957E-004	21.8
72	07	14	5870	3080	0.53	0.04	3.40	00	3.98107E-004	21.8
73	08	15						00		191.3
74	08	16	4270	1430	1.67	0.13	2.75	00	1.77828E-003	191.3
75	WF	WF						NO		
76	01	01	7050	4230	0.61	0.03	3.25	00	5.62341E-004	138.4
77	01	02		680	0.10	0.01	3.35	00	4.46684E-004	138.4
78	02	03		1100	11.60	0.07		00		76.8
79	02	04	1189	660	0.43	0.05	3.15	00	7.07946E-004	76.8
80	03	05	3270	950	0.31	0.01	2.90	00	1.25893E-003	40.2
81	03	06		330	0.20	0.03		00		40.2
82	04	07						00		57.2
83	04	08						00		57.2
84	05	09	1800	670	0.46	0.02	3.00	00	1.00000E-003	34.0
85	05	10	7760	3990	0.33	0.02	3.20	00	6.30957E-004	34.0
86	07	13	7770	4190	0.46	0.03	3.35	00	4.46684E-004	21.8
87	07	14	6540	3560	0.41	0.03	3.40	00	3.98107E-004	21.8
88	08	15		350	1.26	0.08		00		191.3
89	08	16	3350	1240	0.58	0.07	3.15	00	7.07946E-004	191.3
90	WF	WF						NO		
91	01	01	5440	3000	0.40	0.04	3.30	10	5.01187E-004	138.4
92	01	02	1190	700	0.38	0.04	3.50	10	3.16228E-004	138.4
93	02	03		650	7.00	0.34	2.80	15	1.58489E-003	76.8
94	02	04	1200	600	0.32	0.02	2.90	15	1.25893E-003	76.8
95	03	05	3670	1100	0.31	0.03	3.20	05	6.30957E-004	40.2
96	03	06		102	0.56	0.13	3.10	05	7.94328E-004	40.2
97	05	09	2440	850	0.34	0.04	2.70	CO	1.99526E-003	34.0
98	05	10						CO		34.0
99	07	13	7890	4050	0.47	0.06	3.10	05	7.94328E-004	21.8
100	07	14	6550	2900	0.45	0.02	3.20	05	6.30957E-004	21.8
101	01	01	4660	2550	0.33	0.04	3.40	10	3.98107E-004	138.4
102	01	02						10		138.4

row	POND	LYSIM	SO4	FE	NI	CU	PH	TREAT	H_ION	WATER
103	02	03						15		76.8
104	02	04	1120	520	0.20	0.03	3.10	15	7.94328E-004	76.8
105	03	05	3380	930	0.18	0.03	2.70	05	1.99526E-003	40.2
106	03	06						05		40.2
107	04	07						00		57.2
108	04	08						00		57.2
109	05	09	2210	675	0.28	0.03	2.90	CO	1.25893E-003	34.0
110	05	10		2460	0.73	0.40	2.70	CO	1.99526E-003	34.0
111	07	13	16300	730	0.72	0.08	3.00	05	1.00000E-003	21.8
112	07	14	8640	3900	0.83	0.05	3.20	05	6.30957E-004	21.8
113	02	04	861	341	0.21	0.01	3.20	15	6.30957E-004	76.8
114	03	05	2670	486	0.12	0.02	4.00	05	1.00000E-004	40.2
115	05	09	1380	290	0.13	0.01	3.40	CO	3.98107E-004	34.0
116	05	10					3.30	CO	5.01187E-004	34.0
117	07	13	11200	6250	0.46	0.04	2.70	05	1.99526E-003	21.8
118	07	14	5300	2390	0.28	0.02	4.10	05	7.94328E-005	21.8